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EFFECTS OF DISCRETE-TRIAL AND FREE-OPERANT PROCEDURES ON THE ACQUISITION AND MAINTENANCE OF SUCCESSIVE DISCRIMINATION IN RATS

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Rats were trained on a successive discrete-trial discrimination between two tonal stimuli to examine the effects of availability of a lever during intertrial intervals. In the discrete-trial condition, in which a lever was removed from the chamber during intertrial intervals, 10-s trials were initiated by the presentation of both discriminative stimulus and lever. In the free-operant condition, in which a lever was present during both trials and intertrial intervals, 10-s trials were initiated only by the presentation of a discriminative stimulus. Experiment 1 employed 50-s intertrial intervals and demonstrated that discriminative performances were acquired faster and maintained better in the free-operant conditions than in the discrete-trial conditions. Experiment 2 employed 5-s intertrial intervals and showed that poor discriminative performances in the discrete-trial conditions were improved. These results indicate that the presentation of a lever to start a trial can overshadow or mask the control by a discriminative stimulus and thereby obstruct the acquisition and maintenance of discriminative performances. Furthermore, the overshadowing or masking effects are strengthened as a function of the duration of intertrial intervals.

Key words: successive discrimination, discrete-trial procedure, free-operant procedure, overshadowing, masking, lever press, rats

Two different procedures, discrete-trial and free-operant procedures, have been employed traditionally in the study of learning. The discrete-trial procedure is a procedure in which discrete occurrences of a specific, externally controlled stimulus event (e.g., the insertion of a lever in an operant chamber or the opening of a door in a runway) and/or a discriminative stimulus enable an organism to make a designated response. The free-operant procedure is a procedure in which the opportunity to make a designated response is freely available to the organism.

Logan and Ferraro (1970) presented a framework for conceptualizing the relationships between the discrete-trial and free-operant procedures. In their framework, a discriminative stimulus signaling the consequence of responding is distinguished from an enabling stimulus, which refers to an external stimulus event that physically permits a subject to emit the response in question. Within this framework, the typical discrete-trial procedure differs from the typical free-operant procedure in the way of presenting the enabling stimulus. For example, in the typical discrete-trial procedure using a runway, the opening of a door (i.e., an enabling stimulus) occurs only at the beginning of a trial, whereas in the typical free-operant procedure using a chamber, an enabling stimulus such as a lever or a key is presented throughout a session. In other words, the two procedures differ in the availability of an enabling stimulus during trials and intertrial intervals (ITIs): Relatively long ITIs (during which responses are not permitted) are alternated with trials (during which only one response is permitted) in the typical discrete-trial procedure, whereas responses are emitted freely throughout a session in the typical free-operant procedure. Thus, the two procedures are located at opposite ends of the continuum of the availability of the enabling stimulus.

Although Logan and Ferraro (1970) described the runway situation as the typical discrete-trial procedure, it is easy to arrange a discrete-trial procedure using lever pressing or key pecking in an operant chamber (e.g., At-

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nip, 1977; Brown & Jenkins, 1968; Platt, 1971). In these studies, the presentation of an enabling stimulus and/or a discriminative stimulus defines a trial: A response lever, which is retracted from a chamber during ITIs, is presented during trials, or a response key in a pigeon chamber, which is darkened during ITIs (i.e., blackout), is lighted during trials, whereas only a discriminative stimulus is presented during trials when a response lever or key is accessible during trials and ITIs. According to Logan and Ferraro's framework, these procedures are also situated at different positions in the continuum of the availability of the enabling stimulus. Therefore, these procedures may have different behavioral effects.

There are few experiments that have examined the effect of availability of an enabling stimulus on the acquisition and maintenance of learned behavior (e.g., Asano, 1976; Taus & Hearst, 1970). Taus and Hearst varied the duration of a blackout interval between presentations of a 30-s stimulus in the presence of which responses were reinforced on a variable-interval schedule of reinforcement, and found that pigeons' response rates increased in the presence of the stimulus as a direct function of the duration of the intervening blackout. This result suggests that response rate is enhanced as the period in which an enabling stimulus is not available is increased.

Moreover, Asano (1976), with Japanese monkeys, examined the effects of the availability of an enabling stimulus during ITIs on the formation of a successive discrimination. Monkeys were first trained to discriminate between red and white discs in a discrete-trial procedure in which the lever was available only during trials. Then the procedure was changed to a free-operant procedure in which the lever was available during both trials and ITIs. Discriminative performance did not develop under the discrete-trial procedure but did under the free-operant procedure.

The present experiments, using rats as subjects, further examined the effects of the discrete presentation of an enabling stimulus on the acquisition and maintenance of a successive discrimination. Experiment 1 compared a free-operant condition with a discrete-trial condition: In the free-operant condition a lever was present in a chamber during both 10-s trials and 50-s ITIs, whereas in the discrete-trial condition a lever was removed from the chamber during 50-s ITIs. Experiment 2 examined the effects of the two conditions with ITIs shortened to 5 s.

EXPERIMENT 1

METHOD

Subjects

Ten experimentally naive male albino rats of the Wistar strain, approximately 3 months old at the beginning of the experiment, were maintained at about 80% of their free-feeding body weights throughout the experiment. They were housed in individual home cages with continuous access to water.

Apparatus

The conditioning chamber was 25 cm by 25 cm by 31 cm. The ceiling and two sidewalls were made of transparent Plexiglas, and the remaining two walls were of sheet metal. The lever (2.5 cm wide, 0.2 cm thick) was located 6.0 cm from the right sidewall and 5.0 cm from the grid floor, and extended 2.0 cm from the front wall. The lever could be retracted by a 24-V DC solenoid. A minimum force of about 0.15 N was required to operate the lever. A food pellet (about 45 mg) served as a reinforcer and was delivered into a recess (5.0 cm by 5.0 cm by 2.5 cm) located 1 cm above the grid floor on the front wall. A speaker mounted behind the front wall was used to deliver a 500-Hz tone as a positive stimulus (S+) and a 2,000-Hz tone as a negative stimulus (S−) at an intensity of about 85 dB. The illumination in the chamber was provided by one 24-V DC ceiling lamp. The chamber was enclosed in a sound-attenuating chest, and masking noise was provided by an exhaust fan. A logic module system, located in an adjacent room, controlled and recorded the experimental events.

Procedure

A schematic representation of the discrete-trial (DT) and free-operant (FO) conditions is shown in Figure 1. Both conditions contained trials and ITIs. The maximum duration of a trial was 10 s, and the maximum duration of an ITI was 60 s. Each trial was initiated by the presentation of a discriminative stimulus (i.e., 500-Hz tone, S+; 2000-Hz tone, S−). In the DT condition, the lever that had not been presented during the ITI was pre-

sented with a discriminative stimulus at the beginning of a trial. A response during an S+ trial produced the immediate delivery of a pellet, retraction of the lever, and termination of the discriminative stimulus. A response during an S− trial terminated the discriminative stimulus and retracted the lever without the presentation of a pellet. If a response did not occur during a trial, the discriminative stimulus and lever were withdrawn at the end of the trial. The FO condition was the same as the DT condition except that a lever was presented during both trials and ITIs in the FO condition. In the FO condition, each trial was initiated by the presentation of a discriminative stimulus, and a response during a trial terminated the discriminative stimulus with or without the presentation of a pellet on S+ and S− trials, respectively.

Preliminary training. Subjects were initially trained to press the lever by the method of successive approximations. During the next four sessions, every response was reinforced until 80 reinforcers had been collected. Then the subjects were divided into two groups of 5 subjects each, called the DFD (i.e., DT-FO-DT) and FDF (i.e., FO-DT-FO) groups; the only difference was in the order of exposure to the conditions. Each group was trained to press a lever in the presence of an S+ stimulus. This S+-only training was conducted under the DT condition for the DFD group and the FO condition for the FDF group. For both groups, training consisted of 60 trials and continued for six sessions.

Discrimination training. After preliminary training, both groups were given 45 sessions of discrimination training in an ABA design. For the DFD group, discrimination training was first conducted under the DT condition for 20 sessions, next under the FO condition for 15 sessions, and finally under the DT condition again for 10 sessions. The order of the DT and FO conditions was reversed for the FDF group. Each discrimination session consisted of 30 S+ and 30 S− trials, alternated according to a Gellerman sequence. A discrimination ratio was calculated by dividing the number of responses during S+ trials by the total responses during both S+ and S− trials.

Results and Discussion

Table 1 shows the mean number of responses per session on S+ and S− trials in the DT and FO conditions for the DFD and FDF groups. The data were averaged over the last five sessions in each condition. All rats emitted a response on almost all S+ trials of both DT and FO conditions, whereas they responded less often on S− trials of the FO condition than on those of the DT condition.

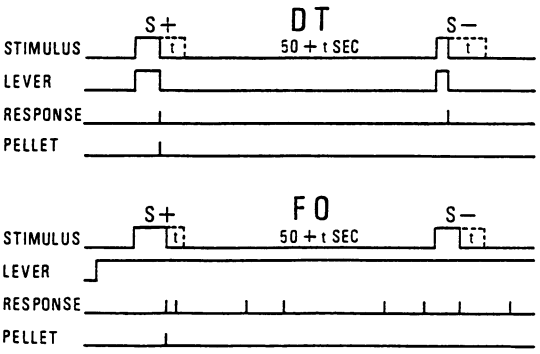

Fig. 1. Diagram of relations between discriminative stimuli, lever availability, responding, and reinforcement under the DT and FO conditions. Upward displacement of lines indicates the onset of event.

Figure 2 shows the discrimination ratios and the number of intertrial responses under the DT and FO conditions for both groups. For the DFD group in the first DT condition, clear differential responding was observed for only 1 rat (R428); discrimination ratios ranged from .58 to .77 in the last session. However, when shifted to the FO condition, all discrimination ratios for all rats abruptly increased and were at least .75 in the last session. In the second DT condition, discrimination ratios were attenuated temporarily and recovered slowly in the later sessions.

For the FDF group, the discrimination ratios showed clear differential responding by the end of the first FO condition. The discrimination ratios were attenuated after the transition to the DT condition and again recovered in the second FO condition. Furthermore, the results of the first condition in both groups showed that differential responding developed faster under the FO condition than under the DT condition. All rats of both groups also emitted intertrial responses in the FO conditions. There were, however, no systematic changes in the number of intertrial responses.

This experiment thus demonstrated that the discrete presentation of an enabling stimulus (i.e., a lever) has a deleterious effect on the acquisition and maintenance of a successive

Table 1

The mean number of responses per session on S+ and S− trials in the discrete-trial (DT) and free-operant (FO) conditions for the DFD and FDF groups in Experiment 1. The data were averaged over the last five sessions in each condition. The standard deviation is presented in parentheses.

DFD group	DT		FO		DT	
Subject	S+	S−	S+	S−	S+	S−
R424	29.0 (1.6)	20.0 (2.0)	29.6 (0.5)	0.6 (0.8)	28.6 (2.3)	12.4 (5.4)
R425	29.8 (0.4)	19.6 (4.4)	30.0 (0.0)	3.2 (2.0)	29.8 (0.4)	10.6 (2.3)
R426	30.0 (0.0)	17.8 (4.6)	30.0 (0.0)	9.0 (3.9)	30.0 (0.0)	15.2 (3.5)
R427	29.8 (0.4)	21.2 (0.8)	30.0 (0.0)	2.4 (1.7)	30.0 (0.0)	21.4 (3.2)
R428	30.0 (0.0)	7.6 (1.5)	30.0 (0.0)	2.4 (1.4)	30.0 (0.0)	8.6 (3.3)
M	29.7 (0.4)	17.2 (4.9)	29.9 (0.2)	3.5 (2.9)	29.7 (0.5)	13.6 (4.4)
FDF group	**FO**		**DT**		**FO**	
Subject	S+	S−	S+	S−	S+	S−
R419	29.6 (0.5)	1.2 (0.4)	29.8 (0.4)	21.2 (3.5)	29.8 (0.4)	0.8 (0.8)
R421	28.4 (1.2)	5.2 (3.0)	30.0 (0.0)	30.0 (0.0)	29.8 (0.4)	6.4 (2.1)
R10	29.8 (0.4)	0.6 (0.8)	30.0 (0.0)	27.4 (0.5)	30.0 (0.0)	0.8 (0.8)
R12	29.8 (0.4)	0.6 (0.5)	29.8 (0.4)	5.4 (2.1)	30.0 (0.0)	0.2 (0.4)
R422	28.6 (2.8)	1.6 (1.0)	29.8 (0.4)	4.0 (1.4)	29.8 (0.4)	1.0 (0.6)
M	29.2 (0.6)	1.8 (1.7)	29.9 (0.1)	17.6 (10.9)	29.9 (0.1)	1.8 (2.3)

discrimination. These results are consistent with those obtained in Asano's (1976) study in spite of some procedural differences; in Asano's study monkeys discriminated between two visual stimuli with ITIs of 30 s, whereas in the present experiment rats discriminated between two tonal stimuli with ITIs of 50 s. The present results thus confirmed the generality of Asano's results.

EXPERIMENT 2

The discrete-trial procedure should come to approximate the free-operant procedure when the ITI (during which an enabling stimulus is not presented) is reduced to zero. If so, the deleterious effects of the discrete presentation of a lever should be attenuated with the ITIs shortened. To examine this possibility, Experiment 2 was conducted with ITIs of 5 s.

METHOD

Subjects and Apparatus

Five experimentally naive male albino rats of the Wistar strain, approximately 3 months old at the beginning of the experiment, were maintained at about 80% of their free-feeding body weights. The same apparatus was used as in Experiment 1.

Procedure

The procedure was the same as that used in Experiment 1 except for the use of 5-s ITIs. The subjects were divided into the DFD and FDF groups and received discrimination training for 45 sessions in an ABA design. Discriminative performance was evaluated by the discrimination ratio obtained from dividing the number of responses during S+ trials by the total responses during S+ and S− trials, as in Experiment 1.

RESULTS AND DISCUSSION

Table 2 shows the mean number of responses per session on S+ and S− trials in the DT and FO conditions for the DFD and FDF groups. The data were averaged over the last five sessions in each condition. On almost all S+ trials of the DT and FO conditions, all 5 rats emitted a response. However, all but 1 rat (R1) responded less often on S− trials of the FO condition than on those of the DT condition.

Figure 3 shows the discrimination ratios and the number of intertrial responses under the DT and FO conditions for both groups. For all 3 rats in the DFD group, discrimination ratios increased gradually toward a value of .88 or higher in the last session of the first DT condition. Two rats (R4 and R1) maintained

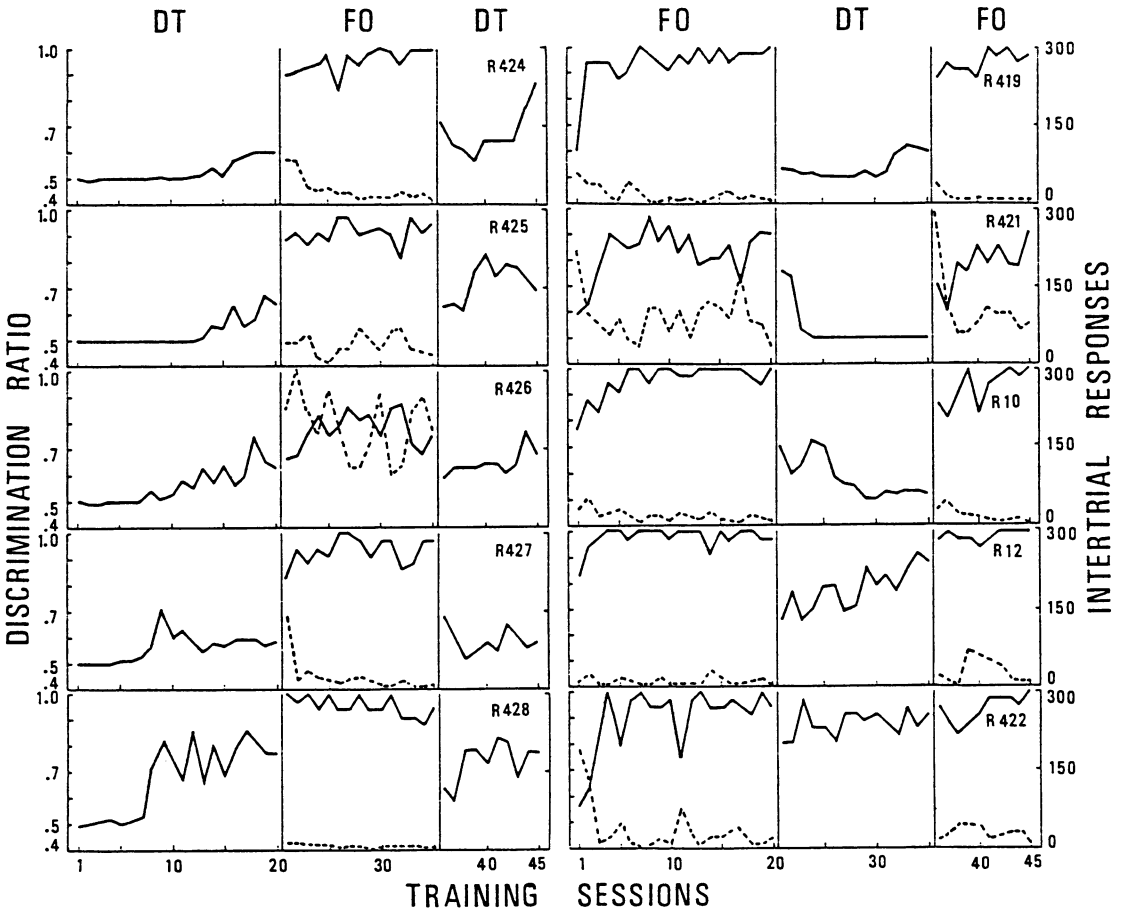

Fig. 2. Discrimination ratios (calculated by dividing the number of responses during S+ trials by the total responses during both S+ and S− trials) obtained from each session of the DT and FO conditions and the number of intertrial responses obtained from each session of the FO conditions. Solid lines indicate discrimination ratios, and broken lines indicate the number of intertrial responses. The data for the DFD and FDF groups are presented in the left and right panels, respectively.

Table 2

The mean number of responses per session on S+ and S− trials in the discrete-trial (DT) and free-operant (FO) conditions for the DFD and FDF groups in Experiment 2. The data were averaged over the last five sessions in each condition. The standard deviation is presented in parentheses.

DFD group	DT		FO		DT	
Subject	S+	S−	S+	S−	S+	S−
R3	30.0 (0.0)	1.4 (0.8)	30.0 (0.0)	0.8 (0.7)	30.0 (0.0)	12.6 (2.2)
R4	29.8 (0.4)	2.4 (1.5)	30.0 (0.0)	1.4 (0.8)	30.0 (0.0)	1.8 (1.3)
R1	30.0 (0.0)	0.8 (0.7)	30.0 (0.0)	1.0 (0.9)	30.0 (0.0)	1.2 (1.2)
M	29.9 (0.1)	1.5 (0.6)	30.0 (0.0)	1.1 (0.2)	30.0 (0.0)	5.2 (5.2)
FDF group	**FO**		**DT**		**FO**	
Subject	S+	S−	S+	S−	S+	S−
R2	30.0 (0.0)	2.8 (1.5)	30.0 (0.0)	29.4 (1.2)	30.0 (0.0)	18.2 (4.2)
R5	29.8 (0.4)	2.2 (1.2)	30.0 (0.0)	6.4 (2.1)	30.0 (0.0)	4.0 (2.0)
M	29.9 (0.1)	2.5 (0.3)	30.0 (0.0)	17.9 (11.5)	30.0 (0.0)	11.1 (7.1)

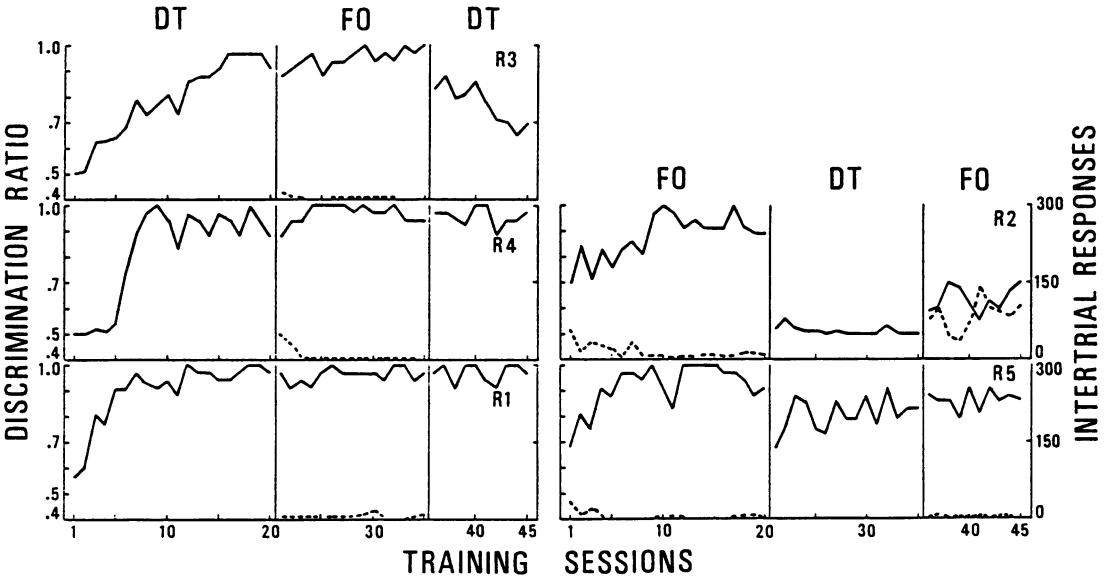

Fig. 3. Discrimination ratios (calculated by dividing the number of responses during S+ trials by the total responses during both S+ and S− trials) obtained from each session of the DT and FO conditions and the number of intertrial responses obtained from each session of the FO conditions. Solid lines indicate discrimination ratios, and broken lines indicate the number of intertrial responses. The data for the DFD and FDF groups are presented in the left and right panels, respectively.

this high level of discriminative performance throughout the FO and second DT conditions. The remaining rat's (R3) discrimination ratios decreased when the procedure was shifted from the FO to the second DT condition.

For the FDF group, the discriminative performances were acquired in the first FO condition. However, discrimination ratios were attenuated in the DT condition and then recovered in the second FO condition. Furthermore, the results of the first condition in both groups showed that discrimination ratios increased a little faster in the FO condition than in the DT condition; the ratios were at least .68 in the first session of the first FO condition for the FDF group, but they were at most .57 in the first session of the first DT condition for the DFD group. However, the level of discriminative performance was about the same in the last sessions of the two conditions. Although the rats were permitted to respond during 5-s ITIs in the FO condition, all but 1 rat (R2) emitted few intertrial responses.

The present experiment with 5-s ITIs thus demonstrated a smaller difference in discriminative performance between the DT and FO conditions than did Experiment 1 with 50-s ITIs: When the condition was shifted from the DT to FO condition and vice versa, only 3 of 5 rats (R3, R2, and R5) showed large changes in discrimination ratios in the present experiment, whereas all 10 rats showed such changes in Experiment 1; the between-group comparison of the first DT and FO conditions also showed that the differences between the two conditions were smaller in the present experiment than in Experiment 1 (compare Figures 2 and 3). These results depended on the differences between discrimination ratios in the DT conditions of Experiments 1 and 2, because the discrimination ratios in the FO conditions were much the same in both experiments. Thus, the deleterious effects of the discrete presentation of an enabling stimulus were attenuated when the duration of the ITI (during which the enabling stimulus was not presented) was reduced.

GENERAL DISCUSSION

Logan and Ferraro (1970) pointed out that the typical discrete-trial procedure differed from the typical free-operant procedure in the availability of an enabling stimulus. The present experiments manipulated the availability of a lever by removing or presenting it during

the ITI and examined the effects of this availability on the acquisition and maintenance of a successive discrimination between two tonal stimuli. Experiments 1 and 2 demonstrated that rats' discriminative performances were acquired faster and were maintained better when the lever was presented during both the trials and the ITIs (i.e., the FO condition) than when the lever was presented only during the trials (i.e., the DT condition). Moreover, examination of the results revealed that poor discriminative performances in the DT condition were improved when the duration of ITIs was reduced from 50 s in Experiment 1 to 5 s in Experiment 2, although discriminative performances in the FO conditions were much the same in the two experiments. Thus, these experiments indicate that discriminative performance varies as a function of availability of an enabling stimulus.

The present results can be understood in terms of an overshadowing effect (in which the presence of a more intense or salient stimulus interferes with the acquisition of stimulus control by a less intense or salient stimulus) or in terms of a masking effect (in which the presence of the former obscures the expression of stimulus control by the latter; Mackintosh, 1977). The difference in discriminative performances between the DT and FO conditions in Experiments 1 and 2 may be interpreted as the presence or absence of the occurrence of overshadowing or masking. In the DT conditions of both experiments, the lever was presented simultaneously with the tonal discriminative stimulus at the beginning of the trials and therefore may have functioned as a predictive stimulus, as in the studies of autoshaping and negative automaintenance with rats (Atnip, 1977; Davey, Oakley, & Cleland, 1981; Myer & Hull, 1974; Stiers & Silberberg, 1974). However, the lever might not have served as a predictive stimulus in the FO conditions of both experiments, because the lever remained in the chamber at all times in these conditions. Thus, the lever may have overshadowed or masked the stimulus control by the tonal stimulus in the DT conditions of both experiments, but not in the FO conditions. Further, the difference in discriminative performances between the DT conditions in Experiments 1 and 2 may be interpreted as the difference in the degree of overshadowing or masking by the lever. As the duration of the ITI (during which the lever was not presented) was increased, the lever may have become a stronger predictive stimulus and overshadowed or masked the tonal discriminative stimulus more completely.

This interpretation is consistent with the predictions from scalar expectancy theory (Gibbon & Balsam, 1981) and from delay-reduction theory (Fantino, 1977, 1981). For example, scalar expectancy theory applied to autoshaping procedures states that the evocative control of a stimulus increases as a function of the ratio of the interreinforcement (i.e., cycle) duration (C) to the trial duration (T). Applied to the present experiments, the C/T ratio is calculated with respect to the temporal relation between the reinforcer and the lever. This ratio was larger in the DT conditions than in the corresponding FO conditions, because the T value (i.e., the duration of a lever presentation) was smaller in the DT conditions than in the FO conditions, although the same C value was used in the two conditions. Accordingly, the lever should have more evocative strength and thus be more likely to obstruct a tonal discrimination in the DT conditions. Also, the C/T ratio can be compared between the two DT conditions in Experiments 1 and 2. This C/T ratio was larger in the DT conditions of Experiment 1 than in those of Experiment 2, because the C value was larger in the former conditions than in the latter conditions, but T values were the same in both conditions. Therefore, the presentation of the lever should have stronger obstructive effects on tonal discrimination in the DT conditions of Experiment 1 than in those of Experiment 2.

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